Testimony to NOAA regarding Ocean Aquaculture

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Summary

Sea-cage farming of carnivorous finfish has been an environmental and social disaster wherever it has been allowed to scale up. Production of each pound of farm fish consumes 4–5 pounds of pelagic forage fish that are an important dietary item in poor countries. Sea-cages function as unintended pathogen culture facilities that amplify diseases from wild fish, causing infection rates in wild fish to increase and wild fish to decline. The sea-cage industry employs many disease specialists with PhD's, but wherever it proliferates, commercial fisheries, subsistence fisheries and sport fisheries are reduced or destroyed, causing loss of social license and widespread public protest. The loss of subsistence fisheries is especially hard on aboriginal peoples.

In order to avoid the mistakes of countries such as Norway and Canada, the following suggestions are offered: (1) Study the aquaculture of other countries directly rather than relying on what is said by their government and industry officials. (2) Understand the ecological principles underlying traditional Hawaiian aquaculture and other aquacultures that have been demonstrated to work over centuries. (3) Remember that, as fish cannot avoid modern methods of capture, the capture fishery is now a form of aquaculture; until it has been restructured for sustainability, no offshore finfish aquaculture should be permitted. (4) Allow Hawaii to manage its own fisheries out to the limit of the EEZ. (5) Be aware that the literature of parasite interchange between farm fish and wild fish in sea-cage aquaculture is contentious for reasons having more to do with commerce than with science. (6) Promote a level playing field for environmentally responsible U.S. aquaculture by advocating countervailing duty tariffs against countries such as Canada that subsidize their aquaculture by permitting environmentally destructive practices.

1. Introduction

My motivation for testifying is that I happen to be from British Columbia, Canada where sea-cage salmon farming has been an environmental and public relations disaster.[3] Everyone there who lives anywhere near it, and is not on the payroll, detests the sea-cage industry with a passion that is difficult to imagine by those who haven't studied the subject carefully.[4,5]

I would be sorry to see the U.S. repeat the mistakes of Canada and the other countries that have uncritically adopted sea-cage fish farming. By the evidence, nobody, absolutely nobody, knows yet how to do open ocean aquaculture in a sustainable way. As currently practiced, sea-cage fish farming is just a disguised capture fishery in which forage fish from the eastern Pacific are ground into oil and meal, adulterated with vegetable material

and shipped thousands of miles to feed carnivorous fish.[6] Commercially, it is the most precarious form of aquaculture since its existence depends on the nutritional and toxicological ignorance of consumers, on low energy prices, and on exchange rates that temporarily allow wealthy nations to purchase an important source of dietary protein in poor nations and feed it to animals.[7,8]

In addition to learning from the aquaculture mistakes of other countries, NOAA could learn from mistakes made in capture fisheries. The lesson from capture fisheries seems to be that centralization of authority leads to regulatory capture, which leads to subsidies, which lead to overcapitalization and eventual destruction of the resource.[9,10]

To help the nation think clearly about the oceans, I hope NOAA will rest the outmoded habit of thought that distinguishes capture fisheries from aquaculture: Technology has now made it nearly impossible for fish to escape capture, and it is now well accepted that capture fisheries require property rights, so the main difference between aquaculture and capture fisheries is the nature of our interference with the life cycle of the cultivars.

Finally, NOAA could learn from the many mistakes made in industrial animal culture.[11]

2. Sea-cage aquaculture in British Columbia

In British Columbia, industrial sea-cage aquaculture passed through five developmental stages, similar to the stages it had gone through in other countries:

Stage (1) a few enterprising individuals start sea-cage farms, and some of them make enough to survive for a few years. The public is generally supportive of the industry, even enthusiastic.

Stage (2) About a million dollars is required to get through a feed cycle. Local bankers hesitate to make loans of that size because they are ill-equipped to lay off the risks of disease and escapes, so founders sell out or become the minority partners of national corporations. Production is scaled up. Coastal residents near farms are alarmed by escapes, eutrophication, killing of marine mammals and unresponsive corporate management. They often succeed in driving the farms to remote areas in which residents have less political influence, but, ironically, are more likely to depend on subsistence fisheries. In remote areas the industry is first welcomed as a potential employer.

Stage (3) Further consolidation occurs as national corporations sell out to multinationals. The multinationals rapidly increase production in a competition for sites. Farms are increasingly automated and employment is reduced. Local governments are conflicted or hostile to the industry. Central governments remain enthusiastic supporters, in part because of *cultural cognition* (e.g., men in suits believe what they are told by other men in suits[12]). Eutrophication of regional waters and declines of wild fish are obvious to long time residents, but governments do not believe them. Local environmental organizations mobilize. Industry denies, deflects, dissembles, 'greenwashes[13]', 'astroturfs[14]', and 'shoots the messenger[15]' whenever possible.

Stage (4) Surprise epidemics occur. Desperate fish farmers implore veterinarians for off-label prescriptions, and some resort to illegal drugs. In many cases, epidemics result in lay-offs of workers, and governments are forced to bail out farmers in order to stave off massive unemployment. Pesticides are approved for use in fish farm feed. Public support for aquaculture turns to disgust and protest, even in areas distant from farms. Governments that supported the industry are reluctant to fund research on the declines of wild fish, and point to other causes. Prominent businessmen in the tourist industry speak out against the aquaculture industry. Governments hold public inquiries staffed mainly by industry supporters and captive scientists. Upscale restaurants and supermarkets cease to serve farm fish. Indigenous peoples sue the corporations for loss of their subsistence fisheries, but lawsuits are quashed by central governments. National and multinational environmental organizations raise public awareness.

Stage (5) Drugs are now routinely used, and pathogens develop resistance. New drugs are needed. Pharmaceutical companies profit. Few wild fish of the cultured species remain, except in areas very distant from farms. New lawsuits, filed by pro bono attorneys with deep pockets and environmental consciences, gain traction. Widespread public protests attract international attention, especially among the young and educated.

My native British Columbia is now at stage (5), and Hawaii is at stage (2) with the 'shoot-the-messenger' aspects of stage (3). The founders of the two sea-cage companies in Hawaii have already sold the majority of their ownership to large corporations.

3. Aquaculture that has been demonstrated to work

Many artisanal systems of aquaculture have been demonstrated to work over centuries. Those systems have certain features in common, which in Hawaii would be referred to as "pono" meaning harmless, righteous or health promoting. The principles of pono aquaculture are:

1. Community buy-in, including local veto power.
2. No use of antibiotics, growth hormones or toxic chemical therapeutants, although vaccination and inoculation are permitted.
3. Simultaneous culture of multiple species (polyculture).
4. Emphasis on herbivores, not carnivores.
5. Natural systems of disease control, such as predators.
6. Locally produced feed, preferably seaweed.
7. Locally manufactured infrastructure.
8. No hatchery fish in ocean systems. Breed fish in the system, or use wild caught-juveniles for grow-out, in order to preserve wild fitness in the inevitable cross-breeding of escaped farm fish with wild fish.[16]

NOAA should support the principles of traditional Hawaiian aquaculture throughout the United States and encourage other countries to do the same, perhaps by international treaty, so that humans do not replicate the mistakes of industrial agriculture in the ocean.

4. Property rights and distributed adaptive systems

Capture fisheries need property rights in order to operate sustainably[17] and property rights in capture fisheries give fishermen the "standing" needed to defend the ocean from abuse. Accordingly, NOAA should strive to convert all capture fisheries to property rights systems. Common property with its associated tragedies is a European concept that is rare in time-tested aboriginal management systems.[18]

It would be a mistake to allocate property rights in offshore aquaculture on other than an experimental basis until we learn how to do it with much less damage to the ocean. Yet, pressure on NOAA to permit offshore aquaculture is intense. To preserve its integrity, NOAA should admit that it does not have all the answers, and promote a distributed adaptive systems model. In other words, allow different regions to make their own rules right out to the 200 mile limit of the Exclusive Economic Zone. As different regions try different strategies in capture fisheries and aquaculture, they will learn from each other's successes and mistakes, and progress will be made.[19] Obvious regional divisions are Hawaii, Alaska, West Coast, Gulf Coast and East Coast

5. Legal issues in Hawaii

There are compelling legal issues peculiar to Hawaii that suggest it should be given responsibility for its own fishery and aquaculture rules. Some legal scholars hold that Hawaii is illegally occupied by the United States,[20] but even if the occupation is legal, State and Federal governments have a fiduciary obligation to protect native Hawaiian land and ocean interests. Moreover, the submerged lands are 'ceded lands' impressed with a trust easement on behalf of the Native Hawaiian people. Discharge of the States' obligation may well require joint management or the assignment of ocean property rights to Native Hawaiians.

6. NOAA's scientific role in aquaculture

NOAA can help by funding science. NOAA should fund experiments in *open-system aquaculture* meaning aquaculture in which the fish of interest are not protected from predators and are free to breed in the wild. An example of such an aquaculture is the feeding of free-ranging fish at an acoustic signal. Another example is the culture of seaweed in the open ocean by man-made rafts, difficult in the oligotrophic waters around Hawaii, but certainly worth investigating. This paragraph is short because I do not claim to know what will work, only what has been demonstrated not to work.

7. The literature of sea-cage farming

In regard of science NOAA should be aware that the literature of sea-cage farming can be very confusing. That is not an accident. Nations that have damaged their fisheries through mismanagement have held out aquaculture as 'the answer' in order to distract voters from their earlier failures, and this has greatly influenced science. For example, in the 1980's

Canada destroyed its northern cod fishery,[21] which for the preceding five centuries had been one of the richest fisheries in the world. About 35,000 fishermen and associated workers in Atlantic Canada lost their jobs.[22] Shortly thereafter Canada's Department of Fisheries and Oceans (DFO) (the federal agency that had mismanaged the cod) embraced sea-cage farming. It signed a Memorandum of Understanding ceding governance of fish farming in British Columbia (BC) (Canada's Pacific province) to the BC Government. With no obligation to conserve wild fish, the BC government was thus incentivized to permit rapid uncritical expansion of sea-cage farming, which it did. To support expansion, DFO pressured scientists at Pacific Biological Station (PBS) (a federal research laboratory) to defend sea-cage farming from its critics. The DFO scientists began to sow confusion in the scientific literature and are still doing so. Their strategy and its execution deserve a book, but two examples will suffice.

Example 1.

Following a rapid expansion of sea-cage farming in BC's Broughton Archipelago, out-migrating juvenile wild salmon suffered an epidemic of sea lice in 2001. Subsequent field studies using standard epidemiological techniques showed that farm salmon in local sea cages were almost certainly the source of the lice,[23] and that conclusion is strongly supported by mathematical modeling.[24] The Broughton Archipelago is an ideal area for such studies because the juvenile salmon migrate down long, narrow inlets, and they can be sampled before and after they pass the farms.

DFO scientists Jones et al. (2006)[25] studied sea lice on three-spine stickleback in the same area. If they had considered the relation of their sampling sites to the 20 salmon farms in the study area, their study might have been good science; but in order to avoid a possible finding that sticklebacks near farms have higher abundances of lice, they ignored the farms—the farms did not even appear on their map of the study area—and aggregated their data over areas sufficiently large to disguise any farm effect. It gets worse: on the 1,309 stickleback that Jones et al. (2006) collected, they counted over 21,000 lice but not a single female louse with eggs, and over 96% of the lice on the sticklebacks were early-stage lice, less than a few weeks old. As salmon lice reproduce continuously, that is very strong evidence that lice were not reproducing on the sticklebacks. As adult wild salmon are absent from the study area, during the time of the study and for six months prior to the study, and as sea lice larvae do not survive more than a few weeks in the water, adult wild salmon cannot have been the source of the lice on the sticklebacks. The probable source of the lice is therefore the 10–15 million farmed salmon present in the study area. Nevertheless, the abstract of their paper states "Sticklebacks appear to serve as temporary hosts, suggesting a role of this host in the epizootiology of [sea lice]." Readers inexpert in the biology of sea lice and salmon were thus invited to conclude that the lice on the juvenile wild salmon might have come from adult wild salmon in autumn with the stickleback as an over-winter host, although the data of the paper point strongly to farm salmon as the proximal source of the lice.

Example 2.

The juvenile pink salmon cohort that suffered the lice epidemic in spring 2001 returned as adults in such small numbers[26] that the BC government mandated a fallow of salmon farms along the migration route in the spring of 2003. It worked better than expected. The pink salmon cohort that entered the water that spring had lower levels of lice and returned as adults in good, though not exceptional numbers in the fall of 2004. Based on the 2004 returns, DFO scientists Beamish et al. (2006)[27] wrote a paper entitled "Exceptional marine survival of pink salmon that entered the marine environment in 2003 suggests that farmed Atlantic salmon and Pacific salmon can coexist in a marine ecosystem on the Pacific coast of Canada." Though written in a scholarly manner, the paper was deliberately misleading in important ways:

(1) It failed to emphasize the importance of the fallow. Of the 21 farm sites in the study area, four were fallowed prior to the out-migration of the juvenile wild salmon, four were treated with SLICE (emamectin benzoate), three held only smolts, and four had been empty for 2.5 months of the prior six-month period due to an epidemic if infectious haematopoietic necrosis (IHN).

(2) The premise of the title is dubious, as the 2004 return of adults was unexceptional.[28] In all population models of pink salmon, survival increases with decreasing size of the parent generation, and the parent generation (adults that returned in 2002) was the smallest since record-keeping began in 1954.

(3) Marine survival is actually unknown; the authors estimated it by attempting to remove the effects of egg retention, spawner mortality and egg-to-fry survival. They used an egg-to-fry survival of 5.6% taken from Table 17 of Heard (1991).[29] The authors describe 5.6% as a mid-range estimate, when in fact Heard gives 16 higher estimates and only 4 lower estimates. Heard's Table 17 gives the value 5.6% for Hooknose creek, a stream without a spawning channel, but as the majority of the salmon in the study area return to the Glendale River, which has a spawning channel, it would have been more appropriate for the authors to have used the egg-to-fry survival for Seton Creek (51.8%–57%) or Jones Creek (42.1%), or even the geometric mean of the 20 egg-to-fry survivals in the Table. The effect of using a low egg-to-fry survival is to inflate the estimate of marine survival.

In summary, there is no scientific basis for concluding that marine survival was very high—egg-to-fry survival may have been high that year—or that survival is as likely to be as high in non-fallow years, which is necessary for co-existence. It is difficult to imagine that this paper had any purpose other than to mislead.

Examples like the two above are the rule rather than the exception,[30] and the pattern of deliberately misleading papers by scientists at DFO has led other knowledgeable scientists to view that institution as a de facto arm of the sea-cage industry.[31,32] The situation is unfair to a Canadian public that reasonably expects government scientists to

be more trustworthy than politicians and industry scientists, and it is unfair to other countries, such as the U.S., that are attempting to chart their own course in aquaculture.

8. Social license

On May 8, 2010 about five thousand people from across BC gathered on the lawns of the BC legislature to protest the presence of sea-cage farms and their destructive impact on wild fish.[33] It was the largest gathering of its kind ever seen in BC. Perhaps 15% of the attendees were aboriginal people for whom wild fish are an important item of food and culture, and the remainder was composed almost entirely of mature, well-educated adults. Most of them had traveled hundreds of miles to attend. One of the speakers was Brian Gunn, President of the BC Wilderness Tourism Association, who talked about the loss of livelihood in the tourist industry due to destruction of wild fish by the sea-age industry. Grand Chief Stewart Phillip, President of the BC Council of Indian Chiefs spoke of the damage to coastal First Nations from loss of their wild fish. Darren Blaney former chief of the Xwémalhkwu (Homalco) First Nation spoke in similar terms, as did Robert Chamberlin, Chief of the Kwicksutaineuk/*Ah*-Kwa-Mish First Nation.

9. NOAA's important role in improving world aquaculture

Wikipedia: "Under U.S. trade remedy laws, foreign goods benefiting from subsidies can be subject to a countervailing duty tariff to offset the subsidy and bring the price of the product back up to market rates."

Wikipedia: "Countervailing duties are duties imposed under WTO Rules to neutralize the negative effects of subsidies. They are imposed after an investigation finds that a foreign country subsidizes its exports, injuring domestic producers in the importing country. According to World Trade Organization rules, a country can launch its own investigation and decide to charge extra duties, provided such additional duties are in accordance with the GATT Article VI and the GATT "Agreement on Subsidies and Countervailing Duties".

NOAA should investigate aquaculture production in other countries, and in cases where production methods are environmentally destructive it should recommend countervailing duties on those products. In particular, imports of farmed salmon from British Columbia should be subject to duties because their production is subsidized by the destruction of wild salmon necessary for tourism, commercial and subsistence fishing and aboriginal peoples. The use of countervailing duties would establish the 'level playing field' necessary for development of an environmentally responsible U.S. aquaculture industry.

10. Myths of sea-cage aquaculture

Finally, I would like to briefly mention some common myths about sea-cage culture of carnivorous finfish.

1. Myth: “Pollution is the big problem.”
Fact: It would be better if all the wastes fell right to the bottom and stayed there, since the currents that disperse wastes from a sea-cage system are the same currents that promote exchange of pathogens between farm fish and wild fish.

2. Myth: “Dilution is the solution to pollution.”
Fact: The lesson of the twentieth century is that dilution is NOT the solution to pollution. Remember the U-shaped response curve: small amounts of many chemicals have a larger effect than moderate amounts of the same chemicals. It is always better to clean up pollution at the source.

3. Myth: “It is needed to feed increasing human populations.”
Fact: All present sea-cage systems culture carnivorous fish. To grow one pound of carnivorous fish, such as the yellowtail grown here in Hawaii, requires the fish oil from four to five pounds of anchovy[34] that would otherwise be eaten by the third world poor.[35] Rational people prefer to eat the anchovy because it has lower levels of persistent organic pollutants, higher levels of omega-3 fatty acids, and superior flavor.

4. Myth: “It produces fish.”
Fact: It converts small nutritious planktivorous fish into larger less nutritious carnivorous fish.

5. Myth: “Opposition to sea-cage aquaculture is fomented by environmentalists.”
Fact: Opposition to sea-cage aquaculture originates with people who have had to live with its undesirable consequences. Environmental organizations respond to those concerns, and as they begin to understand the issue, they steer resources toward it.

6. Myth: “It helps wild fish.”
Fact: Everywhere that sea-cage aquaculture has been scaled up, sympatric congeners have declined. That is true of fish, shrimp, abalone and all other marine taxa under culture. Here is how it works: Wild fish give disease to the farm fish. Protected from predators (the public health inspectors of the ocean), farm fish live on, shedding pathogen into the surrounding ocean. The increased levels of pathogen then cause wild fish to decline. The situation is even worse than it first appears, as sea-cage systems select for greater virulence in pathogens. Bakke and Harris

7. Myth: “Scientists favor aquaculture.”
Fact: Sea-cage aquaculture is a full-employment program for fish pathologists, bacteriologists, virologists and so forth. Financial ties to the aquaculture industry promote a kind of techno-arrogance (*sensu* Meffe 1992) and wishful thinking. The only scientists who seem to be able to think clearly about sea-cage aquaculture are epidemiologists, ecologists with training in the population dynamics of parasites, and (in my experience) physicists and mathematicians. Modern epidemiology, it is worth noting, was invented by Robert (now Lord) May, a physicist who crossed over to biology. The divide may be between those who routinely use calculus and those who do not.

8. Myth: “NOAA should promote sea-cage aquaculture.”
Fact: Promoting sea-cage aquaculture is premature, in view of its problems. NOAA should continue to experiment with aquaculture while rebuilding wild fish stocks.

9. Myth: “Capture fisheries are in irreversible decline.”
Fact: Capture fisheries are a form of open-ecosystem aquaculture—take care of the habitat and then harvest whatever flourishes. Declines of capture fisheries can be reversed by attention to what economists have been telling us for fifty years about the need for property rights in fisheries.[9] NOAA should take the initiative in negotiating with other nations for property rights to straddling stocks and transboundary stocks.

10. Myth: “Sea-cage farming creates jobs.”
Fact: It’s a full employment program for disease specialists with PhD’s but if the experience in my native BC is any guide, it is native Hawaiians who will lose the most from an expansion of sea-cage farming in Hawaii.

11. Myth: “Strict regulation can solve the problems of sea-cage farming.”
Fact: Farms in Norway, Canada, and other countries are very strictly regulated, yet wild fish continue to decline, and eutrophication-related changes continue to increase.

12. Myth: “The U.S. must grow its own seafood to reduce the balance of payments.”
Fact: It is easy to sell seafood cheaply if you produce it unsustainably. The fact that other countries are doing unsustainable things in fisheries and aquaculture is not a good reason to do the same, though it is a good reason to tax seafood imports.

13. Myth: “It promotes food security.”
Fact: Converting 4.5 pounds of imported forage fish into one pound of cultured carnivore promotes food security? The sea-cage industry is famous for unintended comedy, and that is one of its standard jokes. Food security would better be promoted by educating North Americans to eat silver carp and bighead carp which are now rapidly proliferating in the Mississippi basin. Both fish are esteemed in Asia for their flavor and they are planktivores, not bottom feeders.[36]

14. Myth: “It does not change the ocean.”
Fact: Everywhere sea-cage farming expands, wild fish of similar species decline.[37] That is what epidemiology predicts,[38] and that’s been the experience around the world.[39] All juvenile wild fish are planktivores, so when wild fish decline, planktivorous jellyfish are released from competition.[40] Wastes from sea-cage farms often promote plankton, making more food for jellyfish, and some jellyfish are predators of larval fish.[41] Moreover, the cage structures used by sea-cage aquaculture provide additional substrate for the benthic polyp phase of many jellies.[42] Thus sea-cage farming promotes jellyfish in three important ways, and sea-cage farmers are unintended secret agents for the jellyfish of the world. By comparison, run-off from terrestrial aquaculture also promotes plankton, but it does not promote disease in wild fish or provide a substrate for the benthic phase of jellies.

Appendix: Understanding Feed Conversion Ratios

Feed conversion ratios (FCR) are very misleading. In order to get an accurate fish-in fish-out ratio (FI/FO) one must also know the percentage of fishmeal and fish oil in the feed.

A clearly written reference for what really happens is the paper by Tacon and Metian (2008).[6] Since the calculation is important, I will do it here using Kona Blue Water Farms as an example.

The self-reported data for Hawaiian yellowtail (Tacon & Metian, 2008, Table 3) indicate that 1 pound of Hawaiian yellowtail feed includes 0.35 pounds of fishmeal and 0.15 pounds of fish oil. This must be Kona Blue Water Farms, since there are no other yellowtail farmers in the state of Hawaii.

On page 155, top right column, Tacon & Metian (2008) state that
1 pound of pelagic fish yields 0.225 pounds of fishmeal and 0.05 pounds of fish oil.

So the 0.15 pounds of fish **oil** in the pound of yellowtail feed requires 0.15/0.05 = 3 pounds of pelagic fish.

To get the 0.35 pounds of fish **meal** in the yellowtail feed requires 0.35/0.225 = 1.56 pounds of pelagic fish.

However, since the pelagic fish needed for the oil exceeds the pelagic fish needed for the meal, it is incorrect to charge the meal against the farmed yellowtail.

Thus 3 pounds of pelagic fish are required to produce 1 pound of yellowtail feed.

Again from Table 3, the self reported Hawaiian yellowtail FCR is in the range 1.4–1.8, so the pelagic fish to farm fish ratio (the FI/FO) is gotten by multiplying this range by 3. Thus

(1.4)(3) to (1.8)(3) = 4.2 to 5.4

In other words, Kona Blue Water's fish-in fish-out ratio for its yellowtail is 4.2–5.4 not 1.4–1.8. And, according to FAO Fisheries Circular #1018, tuna are worse by a factor of two to three.

Notes and references

[1] I am solely responsible for the views expressed here. As an academic institution, the University of Hawaii does not take positions on the scholarship of individual faculty, and my testimony should not be interpreted or portrayed as reflecting the official position of the university.

[2] Alison Rieser, Professor of Geography at the University of Hawaii at Manoa, kindly assisted with the preparation of this testimony, but any mistakes in it are mine.

[3] The early history of salmon farming in British Columbia is given in the book *Sea Silver* by Keller and Leslie (1996). Subsequent history through 2003 is given in the book *A Stain Upon the Sea* by Hume, Morton, Keller, Leslie, Langer and Staniford (2004). For the U.S. experience, see *Swimming in Circles* by Paul Molyneux.

[4] The people of BC don't blame those who work on the farms – they do the best job they can, and their industry is very highly regulated. Rather, the anger is directed at central governments that allow multinational aquaculture corporations to use the BC coast as a sewer, to the detriment of its wild fish and of the people who depend on them for a living: the tourist industry, native peoples who harvest commercially and for subsistence, commercial and sport fishermen.

[5] Standard techniques from epidemiology, such as Anderson-May theory, explain why sea-cage aquaculture causes local wild fish to decline. Unfortunately, epidemiology requires a lot of mathematics so it isn't part of the standard curriculum in biology. However, a simple probability model gives the same result in the case of macro-parasites.[38]

[6] Tacon, A. G. J. and Metian, M. (2008). Global overview on the use of fish meal and fish oil in industrially compounded aquafeeds: trends and future prospects. *Aquaculture*, **285**: 146–158.

[7] Tacon, A.G.J. and M. Metian (2009) Fishing for feed or fishing for food: increasing global competition for small pelagic forage fish. *Ambio*, **38**: 294–302.

[8] Naylor et al. (2009) Feeding aquaculture in an era of finite resources. *Proceedings of the U.S. National Academy of Sciences*, **106**(36):15103–15110.

[9] *Regulatory capture* is said to have occurred when the regulations favor the industry over the public interest, as when fishermen write the fishing regulations. A *perverse subsidy* is one that has the opposite effect to that intended, as when fishing fleets are subsidized in the hope of producing more seafood but the eventual result is a decline in fish stocks due to over-fishing. *Centralized authority* means that those who make the rules are far away from those who must live by them, as when NOAA officials in Washington make rules

for fishermen in the offshore waters of Hawaii, or when state officials on the island of Oahu make rules for the conduct of aquaculture in an ahupua‘a located on the island of Kauai.

[10] An accessible treatment of the effects of subsidies in fisheries is given by Suzanne Iudicello et al. in their book *Fish, Markets and Fishermen: the economics of overfishing*. For estimates of subsidies to fisheries see various papers by Rashid Sumaila and others. Writing in the *North American Journal of Fisheries Management* Sharp and Sumaila (2009) estimate that the U.S. fishing industry received subsidies of $6.4 billion from 1996 to 2004, not including the costs of fisheries management, port construction and maintenance or subsidy program administration.

[11] Feeding corn to cattle is only the latest of our mistakes in animal culture. Consider: On the grasslands of the North American west we substituted European cattle for 60 million bison and 40 million elk that might have provided protein for even the U.S. population of today if we had managed them correctly. Substitution of one herbivore for others doesn't sound bad, but the cattle hadn't co-evolved with the native prairie grasses. As a result, on over a hundred million acres of the American west the native prairie grasses have now been replaced by cheatgrass and other invasive weeds that do not cure, i.e., they do not retain their protein after freezing or drying, and so cannot support animals through the winter. Ted Turner, who owns more ranch land in the U.S. than anyone else, has turned all his ranches back to buffalo and is trying to bring back the native prairie grasses. The U.S. and other nations should be as smart with the ocean. For original sources see: Manning, R. (1995) *Grassland,* Penguin Books.

[12] See Kahan (2010) Fixing the communications failure. *Nature,* **463**:296–297.

[13] Wikipedia: "Greenwashing (*green whitewash*) is the practice of companies disingenuously spinning their products and policies as environmentally friendly, such as by presenting cost cuts as reductions in use of resources. It is a deceptive use of green PR or green marketing."

[14] Wikipedia: "Astroturfing denotes political, advertising, or public relations campaigns that are formally planned by an organization, but are disguised as spontaneous, popular 'grassroots' behavior."

[15] Wikipedia: "'Shooting the messenger' is a metaphoric phrase used to describe the act of lashing out at the (blameless) bearer of bad news."

[16] Loss of wild fish fitness due to a single interbreeding with hatchery fish has been demonstrated to the second generation. See McGinnity et al. (2009) *Proceedings of the Royal Society B*. doi:10.1098/rspb.2009.0799

[17] Specifically they need at least three things: (1) Fishermen must be confident that the fish they do not catch today will be there for them tomorrow; (2) They must be confident

that poachers and cheaters will be apprehended and punished; and (3) A royalty (tax) on the catch is needed to make fishing unprofitable at stock levels high enough to withstand environmental fluctuation; this royalty also pays for the policing in point (2). See: *The Worldwide Crisis in Fisheries* by Colin W. Clark and other papers by the same author. A more accessible treatment is given by Iudicello et al. cited above. In their book *Fisheries Ecology and Management* Walters and Martell (2004, p. 31) discuss the mechanisms by which government managers and scientists are incentivized to manage poorly. See also: Hilborn, R. (2007) Moving to sustainability by learning from successful fisheries, *Ambio* (2007) **36**:296–303.

[18] For example: Newell, Dianne (1999) *Tangled Webs of History: Indians and the law in Canada's Pacific Coast Fishery*. University of Toronto Press, Canada.

[19] In theories of governance the distributed adaptive systems model is known as the principle of subsidiarity. Wikipedia: "Subsidiarity is an organizing principle that matters ought to be handled by the smallest, lowest or least centralized competent authority."

[20] Van Dyke, Jon M. and Melody K. MacKenzie (2006) An introduction to the rights of the native Hawaiian people. *Hawaii Bar Journal*, July 2006, 63–69.

[21] Hutchings, J. A. (1996) Spatial and temporal variation in the density of northern cod: a review of hypotheses for the stock's collapse. *Canadian Journal of Fisheries and Aquatic Sciences,* **53**:943-962.

[22] Gien, L. T. (2000) Land and Sea Connection: The East Coast Fishery Closure, Unemployment and Health. *Canadian Journal of Public Health* **91**(2):121-124.

[23] This work was led by Alexandra Morton, a whale biologist who taught herself parasitology in order to do the work that DFO ought to have done. Google scholar: Morton + "sea lice" to find her many peer-review papers, many of them co-authored by Richard Routledge, a highly-respected statistician. As all scientists know, if you publish peer-review scientific papers, you are a scientist—not even a high school diploma is necessary—but the sea-cage industry and DFO attempted to discredit her work because she does not have a PhD.

[24] This work was led by Martin Krkosek, then a graduate student at the University of Alberta. Google scholar: Krkosek + "sea lice" to find his many papers in highly regarded peer-review journals. The sea-age industry and DFO also attempted to discredit Krkosek's work.

[25] Jones, S. R. M., G. Prosperi-Porta, E. Kim, P. Callow, and N. B. Hargreaves (2006) The occurrence of *Lepeophtheirus salmonis* and *Caligus clemensi* (Copepoda: Caligidae) on three-spine stickleback *Gasterosteus aculeatus* in coastal British Columbia, *Journal of Parasitology* **92**: 473–480.

[26] Return (= Catch + escapement) of the pink salmon cohort that entered the water in 2001 was the lowest since data collection began in 1953, and survival was lower than any earlier recorded survival by over an order of magnitude. 'Catch' is the number of fish taken by fishermen. 'Escapement' is the number of fish that enter the stream to spawn. 'Survival' is the number of returning adults divided by the escapement of the parent generation. Data from Fisheries and Oceans Canada, mapster website.

[27] Beamish, R.J., S. Jones, C.-E. Neville, R. Sweeting, G. Karreman, S. Saksida, and E. Gordon (2006) *ICES Journal of Marine Science* **63**:1326–1337.

[28] Return of the pink salmon cohort that entered the water in 2003 was lower than that of 19 earlier cohorts and greater than that of 5 earlier cohorts. Survival was lower than that of five earlier generations and greater than that of 17 earlier generations. Data from Fisheries and Oceans Canada, mapster website.

[29] Heard (1991) Pink salmon life histories. In: Groot C. and L. Margolis (eds.) *Pacific Salmon Life Histories*, University of British Columbia Press, Vancouver, Canada.

[30] Frazer, L. N. (2007) Comment on "Sea lice on adult Pacific salmon in the coastal waters of British Columbia, Canada" by R. J. Beamish et al., *Fisheries Research*, **85**:342–345.

[31] Daniel Pauly, possibly the world's most eminent fisheries scientist, tells of going to sea with DFO: "[One of their scientists] said 'We think Alexandra [Morton] is spiking the samples.' I looked around and saw that none of them were smiling, and in that moment I knew they were corrupt."

[32] Although the Canadian public has never understood the implications, the saga of how government fisheries science in Canada was captured by the politicians is a story well known to Canadian fisheries scientists. See: Hutchings, J. A., C. Walters and R. L. Haedrich (1997) Is scientific inquiry compatible with government information control? *Canadian Journal of Fisheries and Aquatic Sciences* **54**:1198–1210. The editor of the journal retired shortly after the paper was published.

[33] I attended.

[34] See the Appendix.

[35] Tacon, A.G.J. and M. Metian (2009) Fishing for feed or fishing for food: increasing global competition for small pelagic forage fish. *Ambio*, **38**: 294–302.

[36] Kolar, C.S., D. C. Chapman, W. R. Courtenay Jr., C. M. Housel, J. D. Williams and D. P. Jennings (2005) Asian Carps of the Genus *Hypophthalmichthys* (Pisces, Cyprinidae): A Biological Synopsis and Environmental Risk Assessment. U.S. Fish and Wildlife Service Rept. 94400-3-0128.

[37] For example: Ford, J.S. and R. A. Meyers (2008) A global assessment of salmon aquaculture impacts on wild salmon. *PLoS Biology*, **6**(2): e33.

[38] Frazer, L. N. (2009) Sea-cage aquaculture, sea lice and declines of wild fish. *Conservation Biology,* **23**(3): 599–607.

[39] Often the evidence is indirect, as in the loss of artisanal and subsistence fisheries even when the competing farm product is too expensive for local consumption or is regarded as inferior by local customers.

[40] Purcell, J.E. and M. N. Arai (2001) Interactions of pelagic cnidarians and ctenophores with fish: a review. *Hydrobiologia* **451**:27–44.

[41] For example: Purcell, J.E. (1985) Predation on fish eggs and larvae by pelagic cnidarians and ctenophores, *Bulletin of Marine Science* **37**(2):739–755.

[42] For example: Lo et al. (2008) Enhancement of jellyfish (Aurelia aurita) populations by extensive aquaculture rafts in a coastal lagoon in Taiwan. *ICES Journal of Marine Science*, doi:10.1093/icesjms/fsm185